SUMMARY OF PROCEEDINGS

EMULSIFIED FUELS PROGRAM REVIEW MEETING

Holiday Inn
Hampton, Virginia
20 March 1968

by

Safety and Survivability Division

US ARMY AVIATION MATERIEL LABORATORIES

Fort Eustis, Virginia

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Mr. Thomas G. Horeff	Federal Aviation Administration
Mr. Howard Jones	US Air Force
Mr. Eugene Davis	US Navy
Mr. Scott Crossfield	Eastern Airlines
Dr. John Dawson	Army Research Office - Durham
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INTRODUCTION

The United States Army Aviation Materiel Laboratories (USAAVLABS) became actively engaged in emulsified fuels research late in 1965. Initially the efforts were quite basic and were designed to establish the feasibility of burning thickened fuel in turbine engines. Having demonstrated the feasibility of this concept, the program was expanded to include investigation of emulsion formulation, combustion characteristics, safety properties, and compatibility with existing selected turbine engine components.

As the program progressed from the theoretical and conceptual study stages to laboratory analyses and field testing, it became necessary to broaden the scope of operations to include efforts applicable to aircraft components and systems compatibility, qualitative and quantitative safety evaluation, more sophisticated combustion experiments, and fuel specification requirements. This wide divergence of effort involved an expansion of contractual and in-house activity and encompassed diciplines of interest to many more individuals and agencies.

As the program effort expanded, it became increasingly difficult to maintain a system of cross dissemination of information between participating and interested agencies. Accordingly, a policy was established whereby program review meetings would be held periodically to present the current status of all efforts to representatives of those organizations participating in or expressing an interest in program participation. These individuals would be permitted to present the results of their efforts, to seek answers to specific questions, to outline their future plans, and to offer criticisms where their analysis of the program direction warranted.

This monograph reports on the preceedings of one such meeting conducted in Newport News, Virginia on 20 March 1968. It should be noted that this meeting was not intended to cover all aspects of the emulsified fuels program; nor, was it intended that other USAAVLABS research efforts dealing with aircraft fire reduction techniques be reported on at this time. Furthermore, this document does not purport to be a verbatim of the day's events; rather, it is a resume' of the principal points of discussion.

SUMMARY OF THE DISCUSSION SESSIONS

In an effort to arrive at an assessment of the meeting, a panel consisting of Mr. I. Irving Pinkel, Dr. John Dawson, Mr. F. P. McCourt, Mr. John White, Mr. Roger Furgurson, Mr. Larry Bell, Mr. William Nolan and CPT George Bowling has prepared the following summary of the discussions. This is not purported to be a verbatim record, but rather the authors' evaluation of the most significant items of discussion.

1. FUEL

a. Cleanliness: Foreign particle contamination of emulsions appears to be a major problem. The primary reasons for this contamination in the past have been poor manufacturing practices and techniques, the corrosive nature of the emulsions, and the poor handling procedures. The opinion was expressed that the level of contamination that is presently seen in the emulsions would be reduced by large volume usage of emulsions. However, the fuel will continue to pick up contamination at transfer points. Large volume use will not be a complete cure for this problem; it will still be significant and one which will probably be worse than the present contamination problems associated with liquid fuels. It was suggested that locating the point of emulsification in a forward area where the emulsions could be manufactured just before they were put into the aircraft might alleviate the contamination problem.

b. Corrosion: This was serious problem with the early formulations; however, significant progress has been made in reducing the corrosivity of emulsions and further work is in progress. It was pointed out that the actual engine and fuels environment may possibly present corrosion problems which cannot be anticipated in laboratory tests. This matter will be given careful attention.

c. Flow Properties: Intuitive reasoning indicates that a higheryield stress emulsion will have superior safety advantages. However, tests to date have yielded little quantitative information in this area. It can be stated that the higher yield stress emulsions will

complicate the problems associated with the extraction of the fuel from the tank. Also, the effective viscosity of the emulsions will govern the pump power required to handle the emulsions. It is apparent that some compromises will have to be made to reach an acceptable range of flow properties. However, it was pointed out that it is very difficult to establish meaningful tests of the safety properties of the emulsions and thus the fuel selection of the flow properties of the emulsions will probably have to be based on systems considerations.

d. Demulsification: The possibilities of demulsifying the emulsions and recovering the liquid JP-4 were discussed. If the JP-4 is emulsified at a rear area, transported as emulsion and then the liquid JP-4 recovered before fueling aircraft, it would affort a degree of protection of the logistical supply system. Additional safety advantage is gained if the emulsion could be loaded on the aircraft. Engine operating problems would be avoided if the emulsion is broken before it enters critical parts of the engine.

e. Specification Development: The present military specification for JP-4 will have to be carefully investigated to determine those portions of the test procedures which will apply to emulsified fuels. Since all the tests were developed for liquid fuels, the applicability of each to emulsified fuels will have to be established. Present emulsions will not pass the thermal stability or coker tests. However, these tests will have to be modified to give true readings on emulsions. Furthermore, additional test requirements such as yield stress will have to be determined.

f. Future Developments: It was pointed out that the fuels which are presently being investigated are first generation products. It is anticipated that as further work is done in establishing requirements, then fuels can be developed which will meet these requirements. However, it is unreasonable to assume that fuels can be developed which will meet all the requirements that present systems may impose. It may be necessary to modify the present systems specifically to accommodate emulsified fuels. The proper course of action will have to be the selection of that compromise which requires a minimum of equipment modification at no sacrifice to the capabilities of the emulsion formulations. The question of cost of the fuels was discussed. It is porrisble at the present time to make a meaningful estimate of these costs but it was suggested that large volumes of emulsified fuels would be at approximately a 10% incremental cost above that of the basic fuel.

2. ENGINES

a. Feasibility Tests: The preliminary engine tests that have been made have conclusively established the feasibility of operation on emulsified fuels. These tests have comprised approximately 100 hours of operation on a variety of engines. With the exception of a sulfidation attack on one engine (attributed to the accidental inclusion of trace quantities of sodium in one formulation), there have been no serious malfunctions reported. These tests were conducted with conventional liquid fuel systems. No modifications were made except for the elimination of some filters and in one case, the changing of the area ratio in a flow divider.

b. False Starts: One phase of operation which appears to present serious problems and which is directly associated with emulsified fuels, is the area of aborted starts. When an engine fails to start on emulsified fuel, the combusion chamber will accumulate significant quantities of emulsion. Subsequent attempts to start will be complicated by this excess fuel and the possibility of a hot start is quite probable. It is apparent that some method will have to be devised to solve this problem.

c. Combusion: The combustion characteristics of emulsified fuels appear to be essentially identical to those of liquid JP-4. It was suggested that there may be subtle differences in the combustion activity at a specific location in the combustor. Also the spray pattern at low flow rates is somewhat different. This may lead to complications for high altitude operation.

d. Fuel Injection Systems: It would appear that emulsified fuels are a practical fuel for use with atomizing fuel injection systems. The vaporizing systems appear to have some problems which would require a significant degree of development to overcome. For this reason, present programs would be aimed at developing atomizing type nozzles which will do a satisfactory job of atomizing emulsified fuels. Comments on the performance of atomizing nozzles indicated that their performance could be improved with suitable design development.

e. Heat Transfer: Due to their viscous nature, emulsified fuels severely restrict the convective heat transfer of the fuel. Thus they may have significant limitations

in heat exchange equipment. This could have implications in oil coolers. This problem could be solved by breaking the emulsion down to liquid before passing it through the heat exchanger.

f. Fuel Control: Although the preliminary engine tests did not incorporate any changes in the engine fuel control, it is suggested that this area may need some redesign. The effects of the buildup of the emulsion in dead spaces of the control may lead to such problems as failure of the static pressure transmitting lines. This area needs investigation and may point to a possible redesign. The problem of fuel flow measurement in test stands has been constantly recurring. However, it does not appear to affect the performance of the fuel control. This is probably due to the fact that the emulsion is at least partially broken by the fuel pump.

g. Corrosion: The corrosivity of the fuel may be compounded by the buildup of emulsion or the residue of broken emulsion in dead spaces in the fuel system. The effects of this phenomenon may not be properly analyzed in the lab testing of the emulsified fuels. Furthermore, the presence of trace elements such as sodium may seriously affect the corrosion characteristics in the engine hot section. The presence of these elements must be closely controlled to guard against a recurrence of the hot corrosion attack which was so damaging previously.

h. Demulsification: It is apparent that a number of problem areas could be eliminated by demulsifying the fuel before it enters the engine. Some effort should be expended to determine if this could be done in a manner which would be feasible, and also to determine what place in the fuel system this could be done without sacrificing the safety advantages of the fuel.

3. SAFETY ASPECTS

a. Small-scale Tests: Emulsified fuels apparently obtain their advantages from two properties: their viscous nature and their retarded rate of vapor release. Tests of the dispersion characteristics of emulsified fuels under low to moderate velocity impact conditions show a reduced area of probable ignition. However, under conditions of high velocity impact, such as a bullet penetration, the fuels react in a manner very similar to liquid fuels.

(1) The lower rate of vaporization retards the formation of flammable mixtures in the tank vapor space. This raises the possibility of reducing tanks vapor space vulnerability by means of vapor space ventilation since the air requirements and the fuel losses would be minimized.

(2) The combustion rates per unit of surface area of the emulsions were found to be essentially identical to those of liquid JP-4. This is primarily because the emulsions tend to break down and a thin layer of liquid forms on top. The one emulsion which did not breakdown to liquid showed a slower vurning rate and was significantly easier to extinguish. The flame propagation rates for the emulsions were significantly reduced, but in a dynamic environment the propagation was still quite rapid.

b. Full-scale Crash Tests: Crash tests with emulsified fuels have demonstrated significant safety advantages for the emulsified fuels. Two identical helicopters were crashed: one with liquid JP-4 in the fuel tanks and one with emulsion in the fuel tanks. The one with liquid fuel burst into flames shortly after impact; however, no fire ocurred in the helicopter carrying emulsified fuel. Two similar tests of C-45 fixed-wing aircraft also showed significant advantages for the emulsified fuel, even in the case where the emulsified fuel was ignited. The airplane with liquid JP-4 in the tanks produced a catastrophic fire which engulfed the airplane The airplane with emulsified fuel in the tanks also had a fire (which started at the right engine), but this fire was contained to the right side of the airplane and was of a much lower intensity than the liquid fuel fire. In the case of the emulsified fuel fire, the occupants of the aircraft would have had little difficulty in evacuating the airplane.

INTRODUCTION

Panel Session

The meeting concluded with a panel session in which the presentations and discussions of the day's proceedings were interpreted by a group made up of representatives of government agencies and organizations directly or indirectly affiliated with safety in commercial aviation. Panel members were:

Mr. Scott Crossfield	Eastern Airlines
Dr. John Dawson	Army Research Office - Durham
Mr. John Enders	NASA - Washington
Mr. Stanley Greene	Aerospace Industries Association
Mr. Jerome Lederer	NASA - Washington
Mr. James Pyle	Aviation Development Council
MG Clifton von Kann	Air Transport Association

A synopsis of the comments made by the panel members is presented below. While these comments are recorded in the first person, they are not to be construed as a verbatim account of each member's discussion. Rather, they should be viewed by the reader as a condensation of those salient points which, in the opinion of the writers are most germane to the subject of universal use of modified fuels in military and commercial aircraft.

Mr. Scott Crossfield - Eastern Airlines:

It is very astounding sometimes the way we lead ourselves in the guise of safety. This trend over the last few years leads me to suggest, nor too facetiously, that our airliner in about five years, with continuing new regulations and additional and never subtracted safety requirements will be a one-passenger C5A airplane.

There appears to be a contradiction in some of the statements today pertaining to engine operation on emulsified fuel with respect to the same factors which are said to be the primary causes of poor operation on liquid fuel. The problem of removing this fuel from the tanks appears to be very significant. Also since this fuel is an ideal cleaning agent and the airlines buy their fuel all over the world, I can envision that we are going to clean the whole world's petroleum distribution system and put it in my airline tanks.

The discussions indicated that we have a whole new propulsion and fuel system technology here along with a whole new and not yet invented group of failure modes. This could be quite unsafe because currently our largest area of attention for safety is in the engine and propulsion system. We are presently using multi-engine aircraft because the most critical source of failure leading to a lack of safety is in the complications of the engine and propulsion system.

It is said that we have to go to the source of these fatalities and that is the fire. Of course, being an old pilot, I agree that we have to go to the source but that is the elimination of the accident that causes the spillage that causes the fire. These comments appear to be very negative but if someone, the FAA for instance, were to allow the airlines to make some trade-off and eliminate some of the present regulations which would be unneeded with an emulsified fuel system, or some other fire prevention system, then I could become a strong supporter of the emulsified fuel and like programs. If you are going to continue to add on these loads, under the guise of safety, with the additional lack of safety that many of these things bring with them because of the additional complexities, and new failure modes, then I think we have got to look very hard at what we are talking about.

Dr. John Dawson - Army Research Office - Durham:

I was concerned over a minor amount of negativity that seemed evident in the meeting this morning. It is true that we have some problems in this particular system but this does not mean that they cannot be solved if one tackles them as they arise.

I think, and this is my own opinion, that a considerable amount of the information that has been developed so far is more qualitative than quantitative. I would like very much to see more of the fine structure of the program developed. It appears to me that the feasibility of the concept has been established and that we are now concerned with the solution of a number of problems that are associated with it. With the exception of some of the information that Mr. Custard presented, it seems to me that the amount of hard data for determining the fundamental phenomena that occur in the process of combustion in a crash is not too plentiful at the present time. If we understood these basic facts and could control the limits of flammability, then we should have a greater flexibility in adjusting a good many other parameters.

I was struck with the number of instances in which problems of corrosion and the effect of impurities appeared to arise. The problem isn't so much concerned with the presence of the impurity or additive but what one can do to control or eliminate it. It seems to me that these are the types of problems which usually can be solved quite easily.

It would seem that the problems associated with the flow of emulsified fuels could be more easily resolved by an expert in the area of fluid mechanics who would bring to bear a more practical viewpoint than would a rheologist although the latter may be invaluable in determining the composition and physical characteristics of the emulsified fuel.

Mr. John Enders - NASA - Washington:

As with most technological advances, the economics of any new safety device will determine its use and, unfortunately, the overall economics of the system with the added device is seldom considered. Jerry Lederer has talked many times about safety being good business when the long-term cost to the airlines is considered. I wondered this morning what difference in attitude we would have noticed if emulsified fuels turned out to be a penny cheaper per gallon than liquid fuel.

The magnitude of the safety conferred on the overall operational system of the emulsified fueled airplane, to my way of thinking, hasn't been really attacked yet. A tantalizingly sufficient amount of data has been developed so far that indicates the desirability of pushing this program to the point where we can say yes or no, go or no go. I don't think that we are at that point yet. I think that we should go ahead with this program until more information is generated since we have an obligation to do everything we can, within our economic constraints, to prevent a catastrophic fire that might be associated with the crash of a jumbo jet. We should consider that significant advances could be made by possibly moving the location of the fuel tanks or making the tanks out of more crash-resistant material so that we could have better fuel containment or at least increase the distance between the fuel and the passengers.

I have two final comments in the form of questions. Can a demulsifying agent be used for clean-up of the fuel control system? Wouldn't this solve some of the problems associated with the emulsion by an admittedly added operational problem associated with this practice? Finally, what are the effects of long term storage? I'm thinking here in terms of general aviation where a plane may fly only once or twice a month.

Mr. Stanley Green - Aerospace Industries Association:

The discussion today has been aimed directly at the military, but, along with the other members of the panel, we in civil aviation are also very interested in the crash-fire problem. This problem will become more acute as airplanes continue to get larger and more complex. The fuel manufacturers must recognize, however, that the next generation of aircraft is already designed and that these aircraft cannot be expected to accept any fuel that is developed. There will also be fuel problems associated with the higher performance aircraft, such as the SST where the fuel is used to cool the wing. You must, however, develop these modified fuels.

We in the Aerospace Industries Association are looking at the problem of post-crash fire in our development program. The major development program objective is directed toward finding better cabin interior materials to alleviate the crash-fire problem. However, it will solve only about 2% of the problem because all we are doing is putting in materials that do not support combustion; materials which are self-extinguishing. The 98% of the problem is the burning 5000 pounds of kerosene that is now saturating this self-extinguishing material.

Unless someone comes up with a means of fighting the problem at its source, the fuel, through containing it or modifying it in some way, we will not be making a significant improvement in the crash-fire problem. Someone must come up with the proper emulsion characteristics, and must lick all of the other associated problems--and the price must be reasonable. When you accomplish this, we will use the fuel because it is the best solution to the problem of crash fires.

Mr. Jerome Lederer - NASA - Washington:

Contrary to the feeling of the other members of the panel, I did not note a strong negative feeling here. In fact, I thought it was much more optimistic than at the meeting we had about a year and a quarter ago. I sense that there is a lot of momentum gathering, that the engine people and oil people are eager to go ahead and that they see no problem given enough time and money; and I hope that this is the case. I am reminded of a similar meeting that I attended in 1930 where much the same arguments that we have heard today were put forth in defending wooden against all-metal airplane construction.

A consideration of the economics of the emulsified fuel must consider the complete system. This would consider such items as cost of insurance premiums, costs of fire-fighting equipment and accident investigations and would evaluate the benefits to be derived through the elimination of some of the present safety devices since they would no longer be necessary. Finally, we must consider that public sentiment will create a tremendous uproar when a jumbo jet crash kills 600 or 700 people. Regardless of the rational arguments about the number of passengers carried versus the number killed, public sentiment just won't let it happen twice without corrective measures.

I think that this should be expedited in every way possible. I have been saying publicly that this should be a Manhattan-type project because of its importance and in order to get it done as quickly as possible. I hope that the momentum associated with the project keeps building up.

Mr. James Pyle - Aviation Development Council:

I would back up particularly what Mr. Crossfield and Mr. Lederer said, but there are several things that I would like to emphasize. The economics of this fuel for civil operation presents a pretty awesome bill. I would support the development of this program on a true systems basis. We might as well recognize the requirements for the higher performance aircraft and develop a fuel which will meet the requirements of 400°F or 500°F for the fuel in the SST. The altitude factor will become important and I assume that this will come into the program in the flight test regime.

There was considerable discussion about the demulsification process and I wonder if this doesn't open up some avenues for the elimination of some of the system problems. The problem of tank cavitation will be very important when it effects holding reserves. I would urge that the FAA select what appears to be an optimum approach to the problem and then pursue that course of action. I consider it in the national interest to avoid going down two parallel courses.

Basically though, I think this is a good program and I commend the Army AVLABS for bringing everyone together and exploring it and laying all the cards out on the table.

MG Clifton von Kann - Air Transport Association:

Approximately one-third of the people killed in airline crashes probably would have survived if it hadn't been for the fire. This indicates a very serious interest in methods of preventing the post-crash fire. The civilian and military have different requirements and it would be well to define the requirements of each before we get into a long-range study. The FAA and the Army should cooperate in this development to avoid a duplication of effort. Based on today's usage rate, if the additional cost of emulsified fuels amounted to one cent per gallon, the additional cost to the airlines would total approximately $60,000,000 per year in domestic service alone. What would this money provide in other approaches to the post crash fire problem? In any event, the research and development should proceed in this program and the FAA and the Army should cooperate.

Mr. Scott Crossfield - Eastern Airlines (Second Comment):

My previous comments may have sounded as though I was not in favor of moving out smartly in the use of emulsified fuels in commercial airlines. This was not my intention. I intended to indicate that unless such application was considered in the total systems context (and some other safety requirements now imposed are removed), the application to commercial airlines could not be fairly considered.

At the same time, I do wish to stress that the military needs are different, and I feel that there is every reason to move out promptly in making applications; this would provide a highly valuable base of technology for future consideration of commercial airline applications.

COMMENTS BY MODERATOR

Mr. I. I. Pinkel
NASA - Lewis Research Center

The work reported in this session answered several of the questions raised during the first industry-wide review of the use of thickened fuels that was held in June 1966. For example, the altitude range of satisfactory engine operation with emulsified fuel has proved to be wider than first supposed. The airplane fuel system problems associated with emulsified fuels are proving to be less formidable than earlier assessments indicated. Also, fine control over the rheological properties of emulsions now holds the promise of property matching of the fuel to the requirements of suitably modified fuel systems. In this way, system operational flexibility can be achieved while maintaining the safety advantage conferred by the use of thickened fuels.

The safety advantage to be gained by emulsions has been evaluated under more realistic conditions and found to be desirable. The systems problems raised by the use of thickened fuels have been brought into sharper focus and appear to be resolvable by development procedures which are standard for the aerospace field. The several solutions proposed for solving the logistic problems of thickened fuels, particularly the contamination problem, require further study.

Much of the earlier skepticism regarding the practicality of emulsified fuels has turned to sentiment in favor of further assessment of this approach to fire safety. The prevailing opinion suggests that the available resources for such work should be marshalled against a single coordinated program.

MONSANTO EMULSIFIED FUELS

By
Jay C. Harris
Monsanto Research Corporation
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Contract Objectives

Phase I:

1. Optimize MEF formulation to provide MEF-1.

2. Improve MEF-1 as to low temperature properties and corrosion control to provide formula MEF-2.

Phase II:

Develop a mechanical and/or chemical means for demulsifying MEF-2 to recover specification grade JP-4 at a rate of 500 gallons per minute.

Contract Compliance

Phase I:

A formulation matrix was developed and over 170 formulas of the tallowamine acetate base were screened for thermal stability at -30° and 140°F. The preferred MEF-1 formulation resulting from the matrix evaluation contained .5 wt. % tallowamine acetate, 1.31 wt. % ethylene glycol, and 2.19 wt. % water.

One approach to an improved formulation for low temperature usage was to add a coupling agent to the formula. It was found that t-butanol and methanol were most applicable but neither was found necessary in subsequent testing.

One facet of the program was to develop several sources of emulsifier base, i.e. tallowamine. Previous tests had all been made on the basis of tallowamine purified by distillation to be free of the potentially low viscosity oleylamine, a concomitant of manufacture. However, tests of this fluid oleylamine gave emulsions which not only were equivalent to tallowamine products, but which also were stable at low temperatures and did not increase drastically in yield stess at the lower temperatures.

Mild steel and cuprous metal corrosion by MEF was excessive. Consequently, twenty (20) candidate inhibitors were tested unsuccessfully. These were added to 2% excess of acetic acid used in the emulsifier.

Another approach was use of an organic hydroxy acid such as glycolic (hydroxyacetic) or lactic as substitutes for acetic. Both were improvements, with preference for glycolic acid. The mild steel corrosion tests with MEF and MEF-1 gave losses of 39 mg while those for MEF-2 showed only .6 mg loss. Other quantitative tests showed a similar reduction in cuprous metal corrosion tests for MEF-2 based on glycolic acid.

Tests of the rate of evaporation showed both MEF-1 and MEF-2 to be essentially the same with the emulsions being about 1/3 that of JP-4 after 6 hours and about 1/8 that of JP-4 in 1 hour.

Investigations of the droplet sizes of the emulsions indicated some coalescence of the droplets but this procedure did not result in sufficient quantitative data to be used as a satisfactory control procedure.

Studies of the emulsifier migration during five days centrifugation at 500 g's showed that some migration does occur. However this was of sufficiently small magnitude to be of little practical significance.

Investigation of the partition coefficient for the emulsifier showed that it would be almost completely dissolved in the external phase if the emulsion is broken mechanically by shear. Tests for the presence of the emulsifier showed less than 20 ppm of the emulsifier remained in the mechanically recovered JP-4.

The final formulation of the MEF-2 is as follows:

	wt. %
Ethylene glycol	1.31
Water	2.19
Oleyl Amine	0.39
Glycolic Acid	0.11
JP-4	96.00

Phase II:

A chemical method which uses ammonia exists which very quickly breaks the emulsion. Its deficiency lies in the fact that the amine is almost entirely dissolved in the fuel: To meet requirements for specification grade JP-4 it must be absent.

Consequently shear methods are under investigation. Using a Waring Blender at high speed indicates that this approach will minimize the amine content of the recovered fuel to less than 20 ppm: Efforts are being prosecuted to improve this method of JP-4 recovery.

REVIEW OF EMULSION DEVELOPMENT

By
Murray S. Cohen
Esso Research and Engineering
Linden, New Jersey

In mid-1966, the US Army Materiel Laboratories awarded a contract to Esso Research and Engineering for the development of a stable fuel emulsion. At that time we formulated a set of goals which have, over the last 1-1/2 years, been largely met. This report summarizes the highlights of this work and points out what remains to be done in the current contract year. Significant problem areas which will be the subject of additional effort are described and finally, we point out those decisions that should be made which are beyond our control but which rest upon policy choices by the Army and other services.

We set out to prepare a fuel emulsion in which the JP-4 content would be maintained at a minimum level of 97% by weight. This emulsion would be essentially a non-aqueous system using pure organic emulsifiers and an organic continuous phase. In this way we could expect the energy of the emulsified system to be essentially the same as JP-4 (actually the energy per gram was $>$ 99% of JP-4 and the volumetric energy was the same as JP-4).

This system was to display a minimum level of stability. It would be unchanged after 30 day storage at ambient conditions and could be cycled from -20°F to +130°F. An ultimate goal of -65°F to +160°F was felt to be accessible and therefore this was imposed very early in the program. The emulsion should display pseudo-plastic behavior with a yield stress $>$ 1000 dynes/cm^2.

We had observed that emulsions which were water based caused higher than acceptable levels of corrosion to materials of construction. For this reason non-aqueous systems were stressed. In addition, we knew of serious deposition problems that occurred with metal containing emulsions (from cationic type emulsifiers) and for this reason we restricted our development to nonionic-type emulsifiers. Minimum levels of vibrational stress (0.2 g force for 24 hours) would not cause phase separation nor would an acceleratory force of 500 g.

The process to be developed should be inherently scalable, at least on the batch size scale and the system should be able to pass a series of tests which show that the emulsion is not only usable in a helicopter engine system but that it does indeed display the requisite safety characteristics expected from the concept of a safety fuel.

We successfully developed a fuel emulsion, WSX 7165, which meets most of these original goals and at the same time we have characterized that problems remain. WSX 7165 has been successfully burned in combustors and has been pumped through fuel systems. It has been produced in greater than 10,000 gallon quantities, the last 6,000 gallons having been made in relatively routine fashion.

Laboratory evidence has been gained which attests to the great reduction (90 to 99%) in the rates of evaporation, flame spread, and burning rate over a wide temperature range. A clear understanding was gained as to how the emulsion breaks up and atomizes when pumped through nozzles. The technique of de-emulsification by high shear when the system is pumped through screens has also been demonstrated.

Current effort now stresses the more practical aspects in the development cycle. We have learned that cleanliness is a significant problem since dirt does not settle in an emulsified system. This requires emulsion process controlls to insure a level of cleanliness not necessary in producing liquid fuels. A wider choice of emulsifiers and continuous phase chemicals can now be used so that cost and complexity can be reduced. Corrosion problems have been significantly reduced and are controllable through the use of additives. This may even allow a replacement of some of the continuous phase by water. At the same time test methods are under development and will serve as a standard for characterizing the quality of the production batches of emulsion.

Combustion studies are underway which will furnish information as to the nature of the emulsion flame and the pattern of heat release during combustion. De-emulsification and coalescence techniques are being refined to maximize the rapid separation of JP-4 from the system. Finally, 5000 additional gallons of emulsion are being produced for extensive safety and engine testing.

Those problems which will remain with us and will be the subject of continuing effort are now recognized as cleanliness control, corrosion, the training of the end user, and reduction of cost. The most significant of these is that of cleanliness control and the training of the man in the field who is responsible for servicing vehicles which will use emulsions.

The remaining problems that must be solved have to await policy decisions by the services. When the decision is made as to where the emulsion is to be prepared, in the field or in the factory, the wisdom of developing field emulsification units can be properly evaluated. Logistic problems will be severe if we consider shipping the emulsion from the refinery site so that this decision entrains with it a specific orientation for the technical effort.

Similarly, the decision as to where emulsions will be used, in aircraft, ground vehicles, helicopters--all of these, some of these or only one of these, heavily affects the attendant technical effort. Pump design, tank design, pipe design are all seriously affected by the type of application. For example, we have only conceptual thinking at present to rely upon for application of emulsions in piston engines.

Finally, the decision must be made as to how the emulsion will be used. Will it be burned as an emulsion or will it be de-emulsified first. Pump design, nozzle design and other hardware considerations will all depend on this choice.

ACTIVITIES OF PETROLITE CORPORATION IN
THE EMULSIFIED FUELS PROGRAM

By
Kenneth J. Lissant
Petrolite Corporation
St. Louis, Missouri

Petrolite Corporation has had an active research program in the area of high-internal-phase-ratio emulsions for the last decade or more. As early as 1958 we suggested this technique as a means of reducing sloshing in rocket fuels. We have worked with the Air Force Rocket Propulsion Laboratory at Edwards Air Force Base in developing emulsifier systems for composite hydrazine-aluminum fuels. For the last three years we have prepared and supplied JP-4 emulsion compositions to various contractors active in the safety fuel program. All of Petrolite's activities in the safety fuel program have been funded in-house.

In cooperation with Air Logistics Corporation of Pasadena, California, we have conducted a number of simple tests to demonstrate the reduced flammability and the pumpability of this type of fuel. We have developed a continuous method of producing high-internal-phase-ratio fuel emulsions and in cooperation with Air Logistics have produced and supplied in excess of 6000 gallons of emulsified fuels for test purposes.

Petrolite's area of expertise lies in its knowledge of the chemistry of emulsion systems, its ability to tailor emulsion properties for specific requirements, and its experience in the production of emulsions on a continuous, commercial basis. We have relied on guidance from the engine and airframe contractors in determining the types of formulations which we have supplied. Our continuing program of research has shown us that the properties of these emulsions can be varied over a considerable range. We are able to prepare emulsions from virtually any hydrocarbon fraction from hexane through mineral oil. We have prepared formulations from JP-4, JP-5, mo-gas, av-gas, ethyl gasoline, diesel fuel, and kerosene - to name a few. We have been able to prepare formulations with yield values anywhere between 500 and 5000 dy/cm^2. We have the capability of preparing either aqueous or "nonaqueous" formulations. Our current research program has been directed toward methods for accurately characterizing the rheological properties of fuel emulsions, with particular emphsis on the

particle size distribution and the variation of effective viscosity with shear rate. We are also studying means of determining at least semi-quantitatively, the shear stability of emulsion formulations.

Briefly, Petrolite's position may be stated as follows: It has been demonstrated that emulsified fuels are more difficult to ignite, and propogate flame more slowly than unmodified fuels in various types of ground tests. Emulsified fuels do not form continuous films on water and therefore should afford comparative safety in naval operations. It has also been demonstrated that emulsified fuels can be burned in diesel and jet engines without sacrificing too much efficiency. Impact tests, sled tests, and certain tests with planes and helicopters have demonstrated that under crash conditions the use of emulsified fuel significantly diminishes fuel dispersal, reduces the intensity of any resulting fires, and contributes to the ease with which fires can be extinguished.

It would seem that the next step is to determine quantitatively how the various rheological properties, such as plasticity and yield value, should be optimized in order to afford a composition which combines as much safety as possible with maximum ease of preparation and handling. We have demonstrated at least one approach to the quantitative determination of emulsion rheological properties and see no fundamental reason why, once the required properties have been determined, formulations cannot be designed to meet the various requirements.

RHEOLOGICAL EVALUATION OF EMULSIFIED JP-4 FUEL*

By
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Approximately 10,000 gallons of emulsified JP-4 (Monsanto formulation) were prepared by the Georgia Division of Thiokol Chemical Corporation for the Army and it was evaluated at the Reaction Motors Division of Thiokol. The evaluation included the measurement of the rheological properties, namely yield stress and apparent viscosity of temperature, as a function of temperature, mixing time and aging. The droplet diameter of the emulsion was also established. In addition the pressure drop across a 20 foot length of 1 inch line was measured and the spray pattern developed after flow through helicopter nozzles (T-55 single and dual orifice) was analyzed.

The results of the rheological study show that both the yield stress and the apparent viscosity of the emulsion increase with decreasing temperature. The yield stress ranged from 775 dynes/cm^2 to 130°F to 7360 dynes/cm^2 at -20°F; the value at 77°F was 905 dynes/cm^2 and slowly decreased to a constant value of 750 dynes/cm^2 after about six weeks storage. The apparent viscosity of the emulsion ranged from 0.8 to 1.7 poise at a shear rate of 1000 sec^{-1} over the temperature range of -20 to 130°F and its mean droplet diameter was 1.4 microns. The droplet diameter decreased slightly during aging (over a three month period) and after reworking with a Hobart mixer.

The pressure drop across an aluminum tube, 20 inches long and 1 inch ID, was about 10 psia at a flow rate of 0.1 lb/sec and did not vary significantly when the yield stress was varied between 1450 to 2950 dynes/cm^2.

The emulsified fuel was flowed through two types of gas turbine atomizing nozzles, a simplex orifice and a dual orifice (used in the T-55 engine) and the spray pattern and droplet distribution within the spray were examined.

*The studies described here were performed on Contract DAAJ02-67-C-0104 for the U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia.

The spray pattern of the simplex orifice was investigated at its normal operating flow rate for the start cycle of 12 lb/hr (105 psid). The emulsified fuel (yield stress of 800 dynes/cm^2) formed a fully developed spray cone which was similar in structure to liquid JP-4. The mean droplet diameter of the emulsified fuel was 50 microns as compared to a value of 45 microns for liquid JP-4. A higher mean droplet diameter (100 microns) was recorded when the yield stress was increased to 2400 dynes/cm^2.

The dual orifice nozzle was investigated at flight idle conditions in which the primary flow rate was 11.1 lb/hr and the secondary flow rate was 3.5 lb/hr, with 10-20 psid pressure drop across both sections of the nozzle. With this nozzle, the emulsion failed to maintain a steady spray cone. The spray pattern varied randomly from an unatomized rod to a fully developed cone. It was believed that, unless the emulsion was broken down before entering the nozzle, a satisfactory spray cone could not be generated.

The following recommendations are suggested for further study of the emulsified JP-4.

1. The effect of temperature cycling and container material on the stability of the emulsion should be investigated.

2. The effect of low temperature on the atomization efficiency of the emulsion should be studied.

3. The emulsion should be completely broken down before entering the nozzle.

4. Standardized procedures should be developed to assess the quality of the emulsion.

EMULSIFIED FUEL PROPERTY REQUIREMENTS

By
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The Army Fuels and Lubricants Research Laboratory's part in the overall fuel emulsion program has as its objectives the definition of emulsion property requirements which are necessary for satisfactory field performance and the application and development of test techniques so that an emulsified fuels specification can be developed. In satisfying these objectives surveillance of all emulsified fuels programs is maintained and physical performance on all the candidate emulsion formulations is conducted. In discussing the emulsified fuel property requirements, an attempt has been made to describe an emulsion in the form that may someday appear in a specification. These properties are shown in Table 1 and do not include the requirements of MIL-T-5624-JP-4 specification or the other properties for which tests are available or the necessity for control is obvious. The properties listed in the table describe the emulsion per se and define the areas in which research is presently being conducted and in which more work will undoubtedly be required in the future. The following is a brief discussion of the properties listed in the table.

Yield Value - Yield value is the definition of the thickness of the fuel and affects both the areas of safety and flow. There is a minimum requirement to provide adequate safety and a maximum value which fuel system can handle. It will also be necessary to control yield value at different temperatures and shear rates. At the present time there is not adequate data to define the maximum and minimum yield value limits.

Effective Viscosity - Since properties, other than yield value, affect flow, controlling effective viscosity at specified shear rates will probably be required to insure adequate flow performance. The basic technology for this requirement has been essentially developed through work by Dr. Lissant and Dr. Philippoff. However, correlation with full-scale systems will have to be made to determine the effective viscosity limits.

Filterability - Filterability will be important, not only for engine systems, but also POL requirements. The property could be expressed in terms of psi pressure drop at rated flow rate through a standard filter element. In addition

to reflecting flow properties, it will offer some indication of the relative ease with which emulsions can be cleaned of solid contaminants. As yet there has been insufficient significant work to enable setting limits.

Emulsion Stability -

Temperature - Emulsions must be stable over the range of temperatures experienced in storage and use. Effective range appears to be from -65°F to +140°F and improvements in emulsions with the past several months indicate that these requirements can be met.

Storage - The storage stability requirement for emulsified fuels will depend primarily on how the emulsion will be used, where they will be made, how they will be transported, etc. At any rate, emulsions must not break down over an extended period of time. Present emulsions appear to meet these requirements.

Shear - Emulsions will require a minimum stability to insure that pumping in the POL system and in the transfer and boost pumps in the fuel tanks will not result in breakdown and could require a maximum limit at which they must break so they may be successfully used in the combustion chamber. Work now in progress at Pratt & Whitney will define to some extent the maximum shear stability limit, whereas, the minimum limit for shear must be defined by further systems work.

Compatibility -

Other Emulsions - Since emulsions of various manufacture will undoubtedly be used, these emulsions must be compatible with each other. Preliminary work in the laboratory has indicated that the present emulsions are compatible.

Hydrocarbons - The various formulations must also be compatible with a wide range of crudes and refinery blends. Cursory evaluations have indicated that there is no significant problem in this area.

Materials - Emulsions must be compatible with all materials used in the engine and POL systems. At the present time, the formulations are corrosive to mild steel and, to some extent, some engine system parts. However, this problem is currently being worked on and significant improvements have been made within the past several months.

Ash Content - This property is meant to protect the engines in terms of combustion blade deposits. At the present time no data is available as to the relevance of this property but the combustion work in progress at Pratt & Whitney will provide data in this area.

Combustion Deposits - If ash content is not sufficient in terms of deposit, erosion, or corrosion, then a small burner apparatus will be necessary to define this requirement. Several tests are available but correlation data with full-scale engines and combustors has not been obtained.

Dynamic Heat Transfer - Some engine systems use the fuel as a coolant and research under static conditions has shown that emulsions are poor heat transfer materials. If the same is true under dynamic conditions, then system re-design will be necessary. However, if some emulsions have better heat tranafer characteristics than others, it will be necessary to control this variable. Research in this area is being conducted at the present time.

It is realized that property requirements, other than these listed here, will be necessary in a specification. However, it is in these areas that it is felt work should be concentrated at the present time.

Table 1. EMULSION PROPERTY REQUIREMENTS

Requirements	Primary Area Affected
1. Yield Value	Safety, Flow
2. Effective Viscosity	Flow
3. Filterability	Flow, Cleanliness
4. Stability	
Temperature	POL
Storage	POL
Shear	Flow
5. Compatibility	
Ref Emulsion	POL
Ref H-C's	POL, Manufacture
Materials	POL, Systems
6. Ash Content	Engine Deposits
7. Combustion	
Deposits	Engine Deposition
Corrosion	Engine Life
8. Dynamic Heat Transfer	Oil - Engine Life

SOME INFORMATION ON THE COMBUSTION OF EMULSIFIED FUELS BASED ON LABORATORY WORK AT PRATT & WHITNEY AIRCRAFT

By
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This work was accomplished under a current program sponsored and directed by the Army Aviation Materiel Laboratories to evaluate the combustion characteristics of three emulsified fuels relative to JP-4. The program consists of two parts, the first of which involves the study of the spray characteristics of emulsified fuels when used in a typical gas turbine fuel system and secondly, the combustion characteristics of emulsified fuels in a typical gas turbine combustor can.

The following list of burner performance parameters were evaluated by the tests: Flame containment, efficiency, temperature pattern factor, exhaust gas analysis, smoke, light off at sea level and altitude, lean and rich stability limits, and burner skin durability. Some amplification of two of the above parameters may be in order. Flame containment is concerned with the determination of the boundaries of the active combustion zone and where its boundaries occur as a function of temperature rise. The burner skin durability is affected not only by skin temperature but also by the temperature gradients that occur around the circumference and length of the burner can. The test conditions for the combustor rig were as follows: burner pressure was maintained at 70" of mercury absolute while maintaining an inlet temperature of 500°F. Burner temperature rises varied from 600° to 1200°. The airflow used was approximately 2 lbs/sec giving this burner a reference velocity of 140 ft/sec. This combustor is a single nozzle burner 5.3" in diameter and is the present bill of materials for the P&WA JT12 engine. As a result of these combustion rig tests the following conclusions were arrived at:

1) That the combustion activity as measured at a station 8" upstream of the burner exit is slightly higher than that for the JP4 baseline, however, the combustion activity as measured at the burner exit indicated no difference between emulsified fuels and JP4.

2) The relative combustion efficiencies of the emulsified fuels and JP4 are considered to be equal over the temperature rises tested. This efficiency had been determined by the measured exit temperature and compared to the ideal rise for the given conditions. Comparision of the exhaust gas analysis test with the 3 emulsified fuels and JP4 have confirmed this conclusion.

3) That the temperature pattern factor is sufficiently similar for emulsified fuels and JP4 at the design temperature rise. However, at the low temperature rise there were indications that a higher spread prevailed for the emulsified fuels. Since this occurs at low temperature rises, it is considered not to be a serious detriment.

4) The relative smoke output of emulsified fuels compared to JP4 are equal to or less than that measured with JP4C under the same conditions.

5) That burner skin durability did not appear to be affected by the use of emulsified fuels. The "polish" skin temperature patterns obtained when operating at 500° burner inlet temperature with the 3 emulsified fuels and the pressure atomizing fuel nozzle were found to be very similar and in some cases identical to that with JP4 fuel. Skin temperature as measured by thermocouples placed on the burner liner hot spots verified that the temperature levels would not significantly change when using emulsified fuels instead of JP4.

EVALUATION OF EF4-104 IN A PRATT & WHITNEY AIRCRAFT JT-12 ENGINE

By
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Pratt & Whitney Aircraft has conducted a 7.9 hour endurance test on a JT-12 engine burning emulsified JP-4 fuel. In this time period, 9 successful emulsified fuel starts were accomplished. One start followed a 4 1/2 day shutdown period.

The engine was installed in a test stand with both the engine and fuel system components in bill-of-material configuration. In addition to normal engine instrumentation, transient recording instrumentation was utilized to allow comparative evaluation of engine operation conducted with both liquid and emulsified JP-4.

With the engine trimmed to JP-12 A-8 engine ratings the following comparative test program was conducted with both fuels:

1. Minimum of three timed starts
2. Stabilized idle point
3. Stabilized intermediate power point
4. Stabilized maximum cruise rating point
5. Stabilized maximum continuous thrust rating point
6. Stabilized takeoff rating point
7. Minimum of three timed accelerations and decelerations between idle and takeoff power

Upon completion of the comparativ performance test phase, endurance testing consisting of two modified 145-minute FAA endurance cycles was accomplished before supply depletion.

As part of the final test phase, an exhaust smoke density survey was conducted. Smoke measurements showed no difference between regular JP-4 and the emulsified JP-4 fuel.

This test demonstrated that engine transient response, stability, speed governing, and starting characteristics were closely equivalent to those experienced during engine operation with liquid JP-4 fuel. A 2.5 per cent increase in thrust specific fuel consumption over liquid JP-4 was noted with emulsified fuel. This represents the approximate level of aqueous and other non-combustibles in the fuel.

The engine operated normally throughout the test with two exceptions. Difficulty was encountered with two "hot starts" following an attempted start with the ignition system inadvertently "locked out" by a test cell safety device. The cause of the hot starts has been tentatively attributed to unpurgeable emulsified fuel in the engine.

To evaluate the condition of the engine hot section in such an instance, an intentional cold engine aborted start was performed upon test completion by pressuring the fuel system for 20 seconds. A hot section inspection was conducted immediately.

The second problem encountered was that of severe dirt contamination due primarily to the detergent action of the fuel. Throughout the test program, fuel system contamination difficulties were experienced. After only 0.37 hours of low power operation on emulsified fuel the engine was shut down to determine the cause of extremely high pump discharge pressure. Inspection revealed severe contamination of all fuel system filters and particularly the full nozzle screens. It was concluded that the contamination originated in the newly installed fuel supply system and that the emulsion being an efficient detergent lifted the mill scale and particulate matter from the lines, held it in suspension, and finally deposited the contaminant on the various screens.

After 4.85 of additional testing, fuel pump discharge pressure levels again increased to a point prohibiting further running. Analysis of this contaminant revealed it to be carbonaceous in nature. It was tentatively concluded that fuel manifold carbonaceous residue due to thermal breakdown from previous runs on regular fuel or emulsified fuel were dislodged by the emulsion and deposited again on the nozzle screens. Following replacement of the nozzles, the test was completed without further incidents.

Upon completion of this test, a complete teardown inspection of the engine and fuel system was performed. Teardown inspection results of the engine failed to disclose any unusual conditions which could be attributed to the use of emulsified fuel. No abnormal deposits, coking, burning, cracking or bowing of hot section parts was evident.

The fuel system teardown was conducted without draining the various components. The presence of emulsion was noted throughout the fuel control. With the exception of several rust deposits noted one day after teardown, no evidence of fuel system distress could be related to emulsified fuel operation. Surface rust was present on all components in varying degrees. The rust deposits were not severe, were removable by wiping and occurred only in non-critical areas. It may be assumed that the high water content of the fuel was the primary cause of rusting.

Based on these test results, it is concluded that it is feasible to operate a JT-12 engine on emulsified JP-4 fuel. It is further postulated that due to the similarities of the JT-12 and other Pratt & Whitney Aircraft engines that they too will operate satisfactorily on emulsified fuel.

LYCOMING EXPERIENCE WITH EMULSIFIED FUELS

By
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A. Lycoming Experience with Emulsified fuels is both extensive and detailed.

It includes:

1. Four engine models have been run a total of 12 hours on three emulsions:

   T 53-L-1, flown on WSX 7165 in a UH-1 helicopter.

   T53-L-11, sea level tests with JD-1.

   T53-L-13, sea level operation with JD-1 and EF4-101.

   T55-L-7C, sea level tests with JD-1.

   The first two engine models have vaporizing combustors, the other two have atomizing combustors.

2. T53 and T55 fuel controls, including fuel pumps and computer sections, have been bench tested on JD-1, WSX 7063, and WSX 7165. The fuel pumps included both standard gear and experimental piston types. The T55 control tests included ambient temperature and -65°F tests on WSX 7165.

3. Fuel system components have been bench tested with all four emulsions. These components include flapper valves, spool valves, pressure regulating valves, leather cup seals, fuel filters, oil/fuel heat exchangers, flow dividers, and fuel injector nozzles of several types.

4. Combustor tests have been run on two model can combustors and a T53-L-13 annular combustor. JD-1, made in two yield stress formulations, EF4-101 and WSX 7063 have been burned.

5. Several flow rate measurement techniques have been tried.

6. We have manufactured JD-1 emulsion with our technicians, and have an understanding of the practical handling problems.

B. The major technical conclusion drawn from these tests is that emulsion is a practical fuel for gas turbine engines with atomizing combustors. The engine's range of operation will be reduced somewhat, to a degree largely a function of how well the engine's fuel system liquifies the emulsion. If emulsified fuel is considered to be necessary for aircraft fire suppression, engines can readily be modified to operate with this fuel for reasonable periods within reasonable limits. However, from the point of view of engine performance alone, emulsified fuel presents no operational advantage. (It is just another headache that we can learn to live with.)

The disadvantages connected with the use of emulsified fuel are several, but it appears that they can all be overcome. The major problems include:

B. 1. Dirt in or picked up by the emulsion. Even fuel systems which can swallow normally specified contamination will require at least coarse filtration, and the filters will have to be designed for low pressure drop with emulsion.

2. Emulsion corrosiveness. Hot and cold corrosion has been and hopefully can continue to be eliminated by proper emulsion chemistry.

3. Poor heat transfer. Since emulsions have notoriously low overall heat transfer coefficients, fuel/oil heat exchanger performance could be affected. Care must be taken in fuel system design to insure that there are no pockets in hot areas in which emulsion could trap fuel long enough for it to heat up and breakdown.

The test program with our T53-L-11 engine indicated that the vaporizing combustor in this model was unstable at low engine speeds. Starting was difficult, ostensibly because of a reduced rate of heat flow into the incoming emulsion. We have concluded that a vaporizing combustor is not as easy to adapt to use emulsion as is an atomizing combustor.

4. Reduced combustion rate of emulsions. Aircraft combustors have demonstrated that they perform quite

satisfactorily on emulsions when the fuel spray contains only 10 or 20% emulsion or the conditions for rapid combustion are favorable. As the emulsion breakdown in the fuel spray is reduced, our tests indicate that flame length increases and combustor efficiency and stability is reduced. This would imply that low power, high altitude engine operation would be limited, unless fuel injector design is altered to increase emulsion breakdown at low fuel flow rates. A promising approach is to use air assist fuel injectors. For example, air assist nozzle E on the attached figure will breakdown emulsion by 50% over the entire flow spectrum when an air pressure drop of 20 psi is used.

5. Fuel control transient response. Lycoming fuel controls have performed very well on emulsions, with the exception of a minor reduction in transient response rate. The presence of entrapped air in the emulsion will accentuate this effect. In addition, very small passages cannot be used to transmit pressure forces, particularly with high shear emulsions.

6. Emulsion flow rate measurement has been an annoying experimental problem. Pressure measurement also becomes significantly more difficult with emulsions.

C. Further immediate effort with emulsified fuel should be primarily of a developmental nature, with sufficient applied research to permit understanding of emulsion flow, breakdown and combustion mechanisms. There have been enough feasibility studies, except in the aircraft tankage and fuel system areas. The first order of business should be the specification of required emulsion characteristics, so that development can proceed on a consistant basis with a common emulsion.

Specific development areas should include:

1. Fuel flow meter development.

2. Optimization of engine fuel system component designs for reliable long term operation with maximum emulsion breakdown in the fuel spray. Heat exchanger performance characteristics must be developed to meet operational requirements.

3. Combustion characteristics relative to emulsion breakdown should be determined, with remedial combustor development effort made as required.

4. Aircraft-engine system tests on the ground and in flight are needed to prove the adequacy of altitude performance, starting capability, and transient operation of modified systems.

5. Metallurgical tests for freedom from hot corrosion of combustor and turbine materials prior to extended engine endurance test programs on emulsified fuels.

6. The proof of all these developmental tests will only come with a major endurance test program on the entire aircraft fuel and power system.

G. E. EMULSIFIED FUEL EXPERIENCE

By
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General Electric has conducted engine test programs on three different types of gas turbine engines:

- o The T64-10, a turboprop engine used in the Army/Buffalo Program.
- o The J79-15, an after burning turbojet engine.
- o The LM-100, a Marine and Industrial adaptation of the T58 helicopter engine.

The T64 emulsified fuel test was summarized in a paper presented by W. J. Crawford at the Society of Automotive Engineers' National Aeronautic Meeting, April 1967, covering the full test experience. The engine operated normally on emulsified fuel with all engine parameters consistent with normal JP-4 and JP-5 fuel. No adjustments were made to the engine for this series of tests, and the test results indicated no change in engine performance level or in the engine hot part condition after teardown. The fuel used here was an aqueous JP-4 emulsion, which demonstrated a severe post-test problem, that of corrosion of the fuel-wetted cold components after long storage. The fuel control has been flushed with normal JP-4 following the engine testing, as well as bench tested after the engine test program; and when finally disassembled for overhaul, a significant amount of emulsified fuel was still present in the control, which resulted in severe corrosion of all of the fuel control components.

The J79-15 was operated at the Air Force Eglin Field Climatic Laboratory and again all engine parameters appeared normal, including successful start at -20°F and normal afterburner light-off and operation. The fuel used for this program was a non-aqueous JP-4 emulsion which pointed up a different problem than noted on the T64 program. After completion of this test, it was noted that the fuel had separated within the tank system during storage, as well as during normal handling. The degree of separation resulted in questionable test results for this program.

The LM-100 test on the industrial-type T58 engine again showed no apparent change in engine operation; however, the test was terminated due to contaiminated fuel. After operation of the emulsified fuel, the fuel filter, an integral part of the engine, eventually by-passed due to excessive contamination with the fuel nozzles finally clogging and causing high fuel manifold pressure. The fuel used here was again a non-aqueous JP-4, and it was concluded that the fuel contaminant was delivered with the fuel, not picked up within the fuel system.

In summary, the problems defined to date by the G. E. emulsified fuel testing are:

- Corrosion of fuel-wetted components.
- Fuel System contamination, which we feel has been largely due to contaminated fuel as delivered and not the direct result of the detergent action of the fuel.
- Emulsification breakdown prior to fuel nozzle, i.e. what constitutes "safe fuel"?

With this as background, it would appear that future programs would be based on the fact that engines to date appear to work reasonably well on safe fuel and the problems defined to date can be solved. Attention should then be given to operational type problems with aircraft fuel systems leading to flight demonstration of modern helicopter systems. This would allow verification of flight and safety capability of emulsified fuel prior to full program commitment.

A VULNERABILITY EVALUATION OF EMULSIFIED FUELS FOR USE IN ARMY AIRCRAFT

By
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This project was performed for the US Army Aviation Materiel Laboratories, Fort Eustis, Virginia by the Falcon Research and Development Company, Denver, Colorado, Contract DA 44-177-AMC-415(T).

Thickened or solidified fuels for use in aircraft have received intensive study during the past five years. Initially, gels were developed and tested for this purpose, and more recently a variety of fuel emulsions have been formulated and subjected to testing in aircraft fuel system components.

The objective of this continuing effort to adapt thickened fuels to aircraft has been a major reduction in the loss of life and property which are associated with crash fires and with combat fires resulting from enemy action. It is clear that many aircraft and many human lives are continuing to be lost in fires following aircraft crashes which would have been survivable from the standpoint of the impact forces alone. Liquid fuels run out of damaged fuel lines and tanks and form large pools of fire under and around the aircraft. Similar leakage of fuel and spreading of fire takes place within aircraft structure following bullet perforation of fuel systems. Solid fuels would resist this disastrous spreading of the fire to the extent that they resist flow from damaged components. The candidate solidified fuels may also be of value in reducing the probability of fire ignition, reducing fire intensity, or increasing the ease of fire extinguishment.

This program sought to evaluate these latter aspects of the emulsified fuels included in the study. The flow properties and apparent viscosity of the fuels have been investigated by the fuel developers and by organizations such as the US Army Fuels and Lubricants Laboratory. Thus, fuel rheology, important as it is to every aspect of fuel use and safety, was not under direct study in this program.

This evaluation of emulsified JP-4 has concentrated upon the fuel properties which relate to the ignition and propagation of fire under the conditions of ballistic attack and survivable aircraft accidents. The specific

areas of study and testing include the following:

1. Fuel combustion rates as a function of air velocity and air temperature.

2. Fuel vaporization rates under closed-tank and vented-tank conditions.

3. Fuel permeability.

4. Fuel dispersion characteristics under conditions of high-velocity ballistic impact and spillage from heights of up to 20 feet.

5. Ease of fuel droplet or spray ignition with various energy sources.

6. Fuel and tank panel behavior when hit by functioned incendiary bullets.

7. Fire extinguishing ease with a variety of extinguishants against a standardized fire.

8. Self-sealing panel performance with fuel emulsions.

The fuels tested included liquid JP-4 and three JP-4 emulsions. These emulsions were designated MEF, EF4-104, and WSX-7165 and were developed by Monsanto Research Corporation, Petrolite Corporation, and Esso Research and Engineering Company, respectively. All but the Petrolite product were developed under US Army sponsorship. The ballistic firing tests employed caliber .30, caliber .50, and 20 mm ammunition sizes and involved fuel tank material responses with conventional self-sealing panels, crash-resistant panels, and coagulant-sealing tank panels.

The WSX-7165 fuel was shown to burn more slowly than liquid JP-4 or the other emulsions tested when the air velocity across the fire was higher than about 20 feet per second. At lower air velocities, all fuels burned at similar rates per unit of fire surface.

The emulsified fuels vaporize much more slowly at 70°F than liquid JP-4. MEF and EF4-104 emulsions took nearly ten times as long to form an explosive fuel-air mixture as did the liquid fuel, and the WSX-7165 took 100 times as long.

The fuel dispersion characteristics of the emulsion were not greatly different from those of liquid JP-4 under the high-velocity impact conditions of the tests. The emulsified fuels did cohere somewhat longer, to form larger fuel droplets and to maintain slightly narrower dispersion patterns.

The regions of most probable ignition were smaller for the emulsified fuels than for liquid JP-4 with both electric spark and hot-metal surface ignitors. Fuel ignitions were accomplished with all ignitors and all fuels under the more favorable conditions.

Tests with incendiary ammunition showed that fuel fires can be started by incendiary rounds functioned outside of all types of tank material in combination with all of the types of fuel tested. The fires produced with emulsified fuels were generally smaller and more easily extinguished than similar fires with liquid JP-4.

Water fog, sand, water, and air were able to extinguish emulsified fuel fires faster and with less extinguishant than was required for similar liquid JP-4 fires. Dry chemical, CO_2, and liquid foam extinguishants were equally effective against all fires.

The emulsified fuels were found to react well with conventional self-sealing tank materials and were much more apt to be retained in a severely damaged tank than liquid JP-4.

The emulsified fuels were prepared from different batches of JP-4 and were prepared by different processing methods, thus care should be exercised in making direct comparisons between these JP-4 emulsions.

It has been concluded from this study that emulsified fuels offer opportunities for greater aircraft survivability from several standpoints. They may be employed most advantageously as a part of a total passive defense system for aircraft fuel.

PERFORMANCE OF EMULSIFIED FUEL IN A FULL-SCALE AIRCRAFT CRASH ENVIRONMENT

By
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During the past year and a half our efforts for the US Army have been directed toward determining how emulsified fuel performs in an aircraft crash environment. The program was divided into two phases as follows:

Phase I - Simulated Fuel Spillage Comparison Tests
Phase II - Full-Scale Aircraft Crash Tests

The primary objective of Phase I was to determine which of three types of fuel emulsions supplied for test by the US Army Aviation Materiel Laboratories possessed the most favorable characteristics in a typical aircraft crash fuel spillage pattern. This typical fuel spillage pattern was established from film records of previous full-scale crash tests conducted by NACA and our organization. A method for duplicating the fuel spillage was developed and the tests were conducted. The results of these tests indicated that there were few discernible differences between the three types of emulsions. However after a detailed comparative analysis, one of the three types did display slight advantages over the others and was selected for the full-scale crash test series.

The full-scale crash test program was conducted in two series. The first series utilized two Cessna Model YH-41 helicopters as the test vehicles. The fuel tanks in one YH-41 helicopter were filled with 59 gallons of liquid JP-4. An auxiliary fuel tank was installed to contain the gasoline required to operate the engine during the test. Large rocks were installed under the fuel tank to simulate a rough terrain impact. The helicopter was dropped from the back of a moving crane impacting an asphalt runway with a horizontal and a vertical velocity of 44 feet per second. The liquid fuel was forced from the tanks during the impact completely saturating the helicopter wreckage. After 2.2 seconds ignition occurred and the resulting fire completely destroyed the helicopter.

The other YH-41 helicopter fuel tanks were filled with 59 gallons of emulsified JP-4 and subjected to the same test conditions. The fuel spillage during the first 0.2 seconds after impact was similar to the liquid test, however, a

noticeable reduction in the spillage area developed after this time. The fuel spillage after the aircraft came to rest was appreciably less than for the liquid JP-4. After waiting two minutes for a "natural" ignition to occur the spilled emulsified fuel was ignited by tossing a lighted torch into the crash area. The resulting fire was noticeably smaller than the comparable liquid JP-4 fire; however, temperatures within the passenger compartment exceeded human tolerance within ten seconds after ignition during both tests.

The second test series utilized a Beech TC-45J fixed-wing aircraft as the test vehicle. Special metal fuel tanks were installed in the wings and filled with liquid JP-4 for the first test and emulsified JP-4 for the second. The aircraft were accelerated along a horizontal track impacting a prepared 30 degree earth slope. Special barriers were built on the front edge of the slope to damage the bottom of the fuel tanks. Massive damage to the bottom of the tanks in both tests occurred which allowed the fuel to be released. The emulsified fuel covered an area only 30 percent as large as the area covered by the liquid fuel. Ignition occurred shortly after impact in both tests. The resulting fire was noticeably smaller during the emulsified fuel test. Temperatures recorded inside and outside the fuselage were also significantly lower during the emulsified fuel tests.

The results of these full-scale aircraft crash tests have indicated that emulsified fuel has the following significant advantages over liquid fuel in an aircraft crash environment:

(1) Emulsified JP-4 fuel tends to remain in the damaged fuel tank thus reducing the spread of spilled fuel and therefore reducing the chances of ignition.

(2) When subjected to a high impact force the emulsified fuel can be mechanically separated into a mist, however, the size of the particles in the emulsified fuel mist is significantly larger than that observed from similar impacts of liquid fuel. Consequently, the likelihood of mist ignition of emulsified fuel is reduced. In addition, when ignition does occur in the emulsified fuel mist, it has been observed that the ignition experiences difficulty in propogating throughout the mist cloud. Examples of ignition occurring and then being extinguished were common in the emulsified fuel tests.

(3) A reduction in the tendency of the fire to propogate throughout the fuel spillage on the ground was also observed. In the emulsified fuel test of the fixed-wing aircraft the left wing although covered with spilled emulsified fuel did not ignite even though a fire was burning in the left engine area no more than two feet away.

(4) The size of the post crash fire during the identical tests was significantly lower for the emulsified fuel spillage. Temperature-time histories showed a definite lag in reaching maximum temperature during the emulsified fuel tests. Unfortunately in both helicopter tests the temperature reached non-survivable limits within ten seconds after ignition. However the cabin temperature inside the fixed-wing wreckage was tolerable for a full minute after ignition in the emulsified fuel test compared to a 20 second limit experienced during the liquid fuel test.

THE FAA PROGRAM ON REDUCTION OF AIRCRAFT CRASH FIRE HAZARDS

By
Thomas G. Horeff, Program Manager, Propulsion
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Washington, D. C.

The FAA efforts in the area of post-crash fire are also concentrated toward improved fuel containment and the selection of an optimum modified fuel which offers the best tradeoffs between crash fire reduction effectiveness and transport aircraft and engine system compatibility. There are other projects related to the use of low concentrations of Freon 1301 as a cabin fire suppressant, increased fire resistance of cabin materials, and improved passenger evacuation techniques, but only the containment and modified fuel efforts will be reviewed in this presentation.

Our crashworthy fuel tank development work involves integral tanks and improved bladder cell materials, considering aircraft types in which bladder cell installations will continue to be pertinent. Close cooperation between USAAVLABS and FAA has insured progressive continuity of these programs.

Recent work at the FAA NAFEC Atlantic City Test Center involved impact tests of a four-tank bladder-cell fuel system installed in a DC-7 wing panel. It was crash-tested by swinging the wing into obstructions at about 30 mph. The bladder material was ARM-021 Tuffwal - the material which AVLABS successfully developed. The interconnecting plumbing was equipped with FAA-designed isolation valves and activating lanyards to control fuel spillage from broken lines. The test, in which repeated impacts were required to penetrate the fuel tank bay, resulted in no spillage of fuel, complete and satisfactory action of all lanyards and valves, and minimum damage to the bladder cells themselves. Because of the success of these tests, the ARM-021 bladder cell installations will be impacted at higher speeds - up to 100 mph in the near future.

A crashworthy concept being investigated for integral fuel tanks is the application of tough elastic liners for the interior front and lower surfaces of the tanks to improve fuel containment when the tank is subjected to penetrating objects and fractured structure during the crash

sequence. The materials and parting media are being developed by the Firestone Tire and Rubber Company under contract. One of the materials presently undergoing evaluation is nitrile rubber and has the capability of elongating as much as 800 percent. The materials would be applied to the interior of the integral tanks by techniques which would allow the liner to progressively separate from the tank surface so that the penetrating object and surrounding areas would be enveloped in a way that would minimize the spillage of fuel. Although this contract is in its early stages, the initial development has been encouraging. The most successful material will be crash impact-tested at low and high speeds at a later date.

Consistent with military interest in thermally reticulated polyurethane foam, the FAA recently investigated the material as a means of improving the crash resistance of integral tanks. F-86 drop tanks filled with this material and with JP-4 fuel were impact-tested at 80 mph on a dirt mound in the presence of an ignition source. Results indicate that the foam decreases the size and thermal flux of the "fire ball" accompanying the impact, but the reduction is not sufficient within the emergency evacuation time scale to be meaningful. This technology will be further studied in the Firestone contract effort.

The selection of an optimum modified fuel will be based upon overall consideration of the results of the emulsified fuel program sponsored by USAAVLABS, the FAA gelled fuel program, and the self-funded efforts of various petroleum and chemical companies. We believe that the optimized fuel for commercial applications should not be selected until all potential candidates have been developed and evaluated to the extent permitted by available funding. Since the Army was sponsoring a thorough program on development of fuel emulsions, we decided that a further concurrent look at gelled and other controlled flammability fuels was warranted to assure that the latest thickened fuel technology, including the latest emulsion technology, is taken into account in selection of the optimized fuel. While we acknowledge certain advantages of emulsions, we hold no firm opinion at this time concerning whether the optimum fuel will be gelled or emulsified since some gels might have an advantages from a crash fire reduction viewpoint without severe system compatibility disadvantages.

We hope to be in a position later in 1968 to make this selection when the coordinated efforts in the current FAA program of The Western Company and the Bureau of Mines and the anticipated effort of McDonnell Douglas reach appropriate decision points. The Western Company will screen gels, thickened fuels, viscoelastic fluids, and inhibited fuels

and will conduct laboratory tests to compare the fire reduction effectiveness of each candidate fuel with other modified fuels. These laboratory tests will be based on fire hazard test specifications derived from a tentative crash fire rating system recently developed by the Bureau of Mines.

A contract is expected to be awarded in the near future to McDonnell Douglas to study the compatibility of the best candidate gelled and emulsified fuels with jet transport and engine fuel systems. The timing of this study should allow an early input from an aircraft fuel system compatibility viewpoint to be made in the selection of the optimum fuel, while the remainder of the study will be devoted to compatibility aspects of the optimum fuel. McDonnell Douglas will use data from The Western Company and from engine component tests being conducted by Pratt and Whitney Aircraft from the Army and by the Naval Air Propulsion Test Center, Philadelphia, Pennsylvania, through an interagency agreement with the FAA. Turbine engine fuel nozzle, fuel control, and combustor operating characteristics are being determined when gelled and emulsified fuels are used and detailed performance data are being established. The combustor tests with gelled fuel were recently completed and covered test conditions ranging from sea level cold start to lean and rich blowout at altitude. These tests indicated that there is no significant change in combustor performance when using gelled fuel. Temperature rise, combustion efficiency, and combustor exhaust temperature profiles were not affected at the test sea level and altitude pressure and temperature conditions.

Our future plans call for the conduct of a full-scale modified aircraft fuel system ground tests and preliminary engine tests with the optimum fuel if it appears that the use of this fuel may be feasible by current aircraft through minor modifications or at least by next generation aircraft. Concurrently with these tests, we plan to perform a study of the optimum fuel commercial production and distribution requirements to determine the changes and costs which may be necessary to enable the optimum fuel to be used in commercial aviation. The scope of this study will be dependent upon whether the fuel will be modified at the refinery or at the use point. It should provide appropriate inputs together with the results of the system compatibility study into a cost/benefit analysis to evaluate the overall effectiveness of the use of the optimum fuel as compared to crash resistant fuel tanks and other proposed methods for reducing the crash fire hazard. The ground tests and this analysis will establish whether the final demonstration of the optimum fuel should be a flight test program to evaluate inflight fuel system reliability.

EMULSIFIED FUEL PROGRAM STATUS

By
E. C. Davis
Naval Ship Engineering Center
Washington, DC

The only work funded by the Naval Ship Engineering Center on emulsified fuels was a test of the LM100 turbine engine. The Navy arranged with the Army USAAVLABS to have them contract with General Electric to conduct the test. This engine is used in the Bell Aircraft aircushion vehicle and the specific engine tested had just completed 329 hours of service in Vietnam. Nine hours and thirty-two minutes of the total of eleven hours and thirty-seven minutes operating time was with Esso's WSX 7165 emulsified fuel. The Army AVLABS furnished the fuel. Engine starting on emulsified fuel created no problems and fuel consumption rate was very close to that of JP-4 under the same steady state engine conditions. Running time was limited because of fuel nozzle clogging. Clogging was caused by dirtier than normal fuel. Additional fuel filtration was required in order to continue the test. The official report from General Electric has not yet been received. If GE recommends testing in the actual vehicle the Navy plans to investigate with Bell Aircraft the possibility of making a test run with emulsified fuel in the aircushion vehicle.

Since the Army Aviation Materiel Laboratories are covering the area of emulsified JP-4 NAVSEC's program anticipated the development of an emulsified gasoline (MIL-G-3056). It was felt that such a fuel could add a measure of safety to small boat operation. If this were proven to be true it would give the gasoline engine a more competitive position with the much heavier diesel engine when safety was not the overriding consideration. However, when the program was considered for funding the limited application of gasoline engines in future ship building programs made it necessary to give a low priority to the emulsified gasoline program. This means that it will not likely be funded.

There is a question I have concerning the emulsified JP-4. What will salt water do to this fuel? The Navy could not handle a fuel without getting salt water in it. I have not seen a reference to date on any capability test of the emulsion with salt water.

An area that the Navy is interested in and may take a look at, is the property of the emulsion to pick up and hold particulate matter and water. It seems to be a natural for cleaning up fuel systems and especially hydraulic systems. This area of emulsions appears attractive.

The Naval Ship Engineering Center is interested in emulsified fuels JP-4, JP-5 and diesel. It is felt that a contribution to safety in small boat operation is possible and we are interested in and support the efforts of Mr. McCourt and his capable team. We appreciate being kept informed of their progress on emulsified fuels.

LIST OF ATTENDEES

Name	Organization
Adams, MAJ	CDC Supply Agency, Ft. Lee, VA
Adenstedt, Dr.	Lycoming Division, AVCO Corp
Baker, Sam	Bell Helicopter Company
Baxter, Neil	Thiokol Chemical Company
Beardell, Dr. Anthony	Thiokol Chemical Company
Beerbower, Alan	Esso R&D Company
Bell, Larry	USAAVLABS
Bowling, G. W.	USAAVLABS
Brahm, Clay	Petrolite Corporation
Burton, CMDR Lou	USNR
Carroll, Don	AvSER Facility
Castero, Nick	USAMC
Christensen, Lee	McDonald-Douglas Corporation
Cohen, Dr. Murray	Esso R&D Company
Crawford, Bill	General Electric Company
Crossfield, Scott	Eastern Airlines
Custard, George	Falcon R&D Company
Davis, Gene	USN
Dawson, Dr. John	Army Research Office - Durham
Eaffy, Allan	USAF
Eckhardt, John	USN
Efting, MAJ	TAC, Langley AFB, VA

List of Attendees (Cond't)

Enders, Jack	NASA - Washington
Enoch, W. K.	Bell Helicopter Company
Furgurson, Roger	USAAVLABS
Futch, Howard	USAMC
Garabedian, Charles G.	USATAC
Gray, J. T.	Army Fuels & Lubricants Lab
Greene, Stanley	Aerospace Industries Association
Harr, George	Air Logistics Corporation
Harris, J. C.	Monsanto Research Corporation
Hewgley, LTC	USN
Hewin, L. M.	USAAVLABS
Horeff, Thomas G.	FAA
Inglee, Clint	Boeing Company
Jackson, John	General Electric Company
Jefferson, T. E.	Fort Belvoir, VA
Johnson, George	USAMC
Jones, Howard	USAF
Jordan, L. W.	Tecfilms, Inc.
Knick, CMDR V. R.	USN
Koblish, Ted	Pratt & Whitney Aircraft
Kouchoukos, LTC	Combat Developments Command
Kutzko, Gus	General Electric Company

List of Attendees (Cond't)

Lamart, Robert	Chandler-Evans Corporation
Lederer, Jerome	NASA - Washington
Lissant, Dr. Kenneth	Petrolite Corporation
Maggitti, L.	USN
Munroe, MAJ	USABAAR, Ft. Rucker, AL
McArthur, Arthur	Boeing-Vertol
McCourt, F. P.	USAAVLABS
Nault, Hazen	Sikorsky Aircraft Corporation
Nixon, Dr. Jim	Esso R&D Company
Nolan, William J.	USAAVLABS
Norby, LTC	HQ, USAF Systems Command
Ohm, Gerald	Boeing Company
Opdyke, George	Lycoming Division, AVCO Corp.
Pinkel, I. I.	NASA - Lewis Research Center
Proudman, Ernest	USAMC
Pyle, James	Aviation Development Council
Quillian, Roy	Army Fuels & Lubricants Lab
Roberts, Roger	Pratt & Whitney Aircraft
Salb, F. E.	Allison Division, GM Corp.
Stewart, George	Air Logistics Corporation
Streets, Ron	USAMC

List of Attendees (Cond't)

Tate, R. W.	Delevan Corporation
Taylor, Roger	CDC, Ft. Rucker, AL
Tvede, CMDR	Norfolk Navy Flt Safety Center
van Nimwegen, R. R.	Garrett Corporation
von Kann, MG Clifton	Air Transport Association
West, A. A.	General Electric Company
White, John	USAAVLABS
Whitlock, LTC K.	US Army
Williams, Bob	Boeing Company - Witchita

NOTE: The omission of any name from the above list is unintentional: the original roster of attendees was inadvertently misplaced and this listing was compiled from memory.